Understanding and Addressing High-penetration PV Issues Through Analysis of PV Integration in Florida Utility Circuits

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Workshop:

Achieving High Penetrations of PV: Streamlining Interconnection and Managing Variability in a Utility Distribution System

Dept. of Energy, EPRI, Sandia National Labs, National Renewable Energy Lab

SPI 2012

Orange County Convention Center
Orlando, FL
September 14, 2012

Sunshine State Solar Grid Initiative (SUNGRIN)

- DOE EERE High-Penetration PV Deployment
- 5 year / 5 phase project
- In partnership with Florida utilities
- PV resource variability
- High penetration in different circuits
  - Basic understanding
  - Tools
  - Solutions
- Outreach, Engagement, Knowledge & Tech Transfer

Center for Advanced Power Systems

Florida Solar Energy Center

FPL

FMPA Florida Municipal Power Agency

FRCC Florida Reliability Coordinating Council, Inc.

GRU More than Energy

JEA

Lakeland Electric Your Essential Link to a Quality Life

OUC The Reliable One

OSIsoft.

SMA

U.S. Department of Energy | Energy Efficiency & Renewable Energy

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Studying Florida Circuits

JEA Brandy Branch –
PSEG Jacksonville Solar

GRU
- 6th Street Solar
- 53rd Ave.

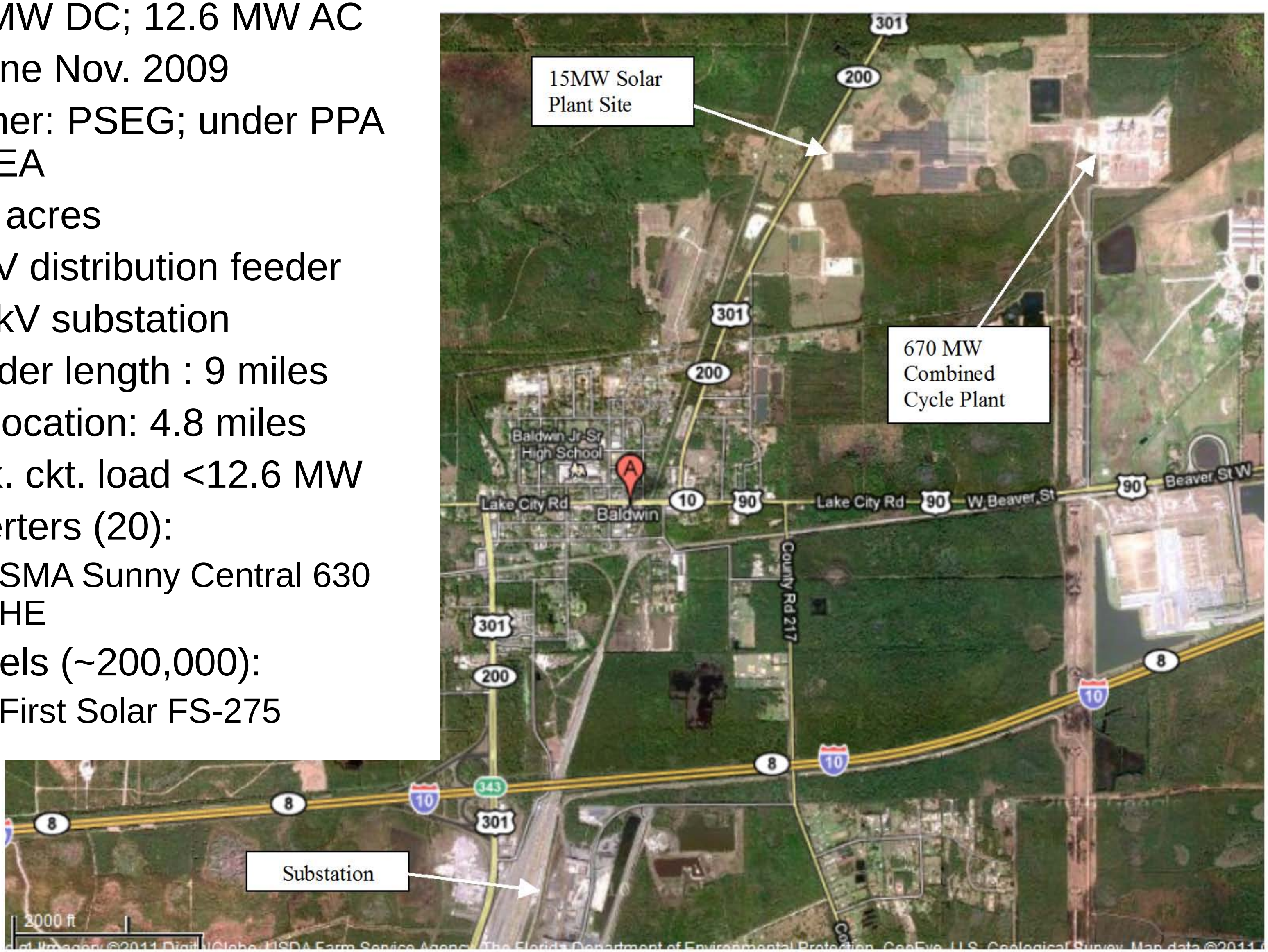
OUC Stanton
Energy Center

NASA KSC
(w/FPL)

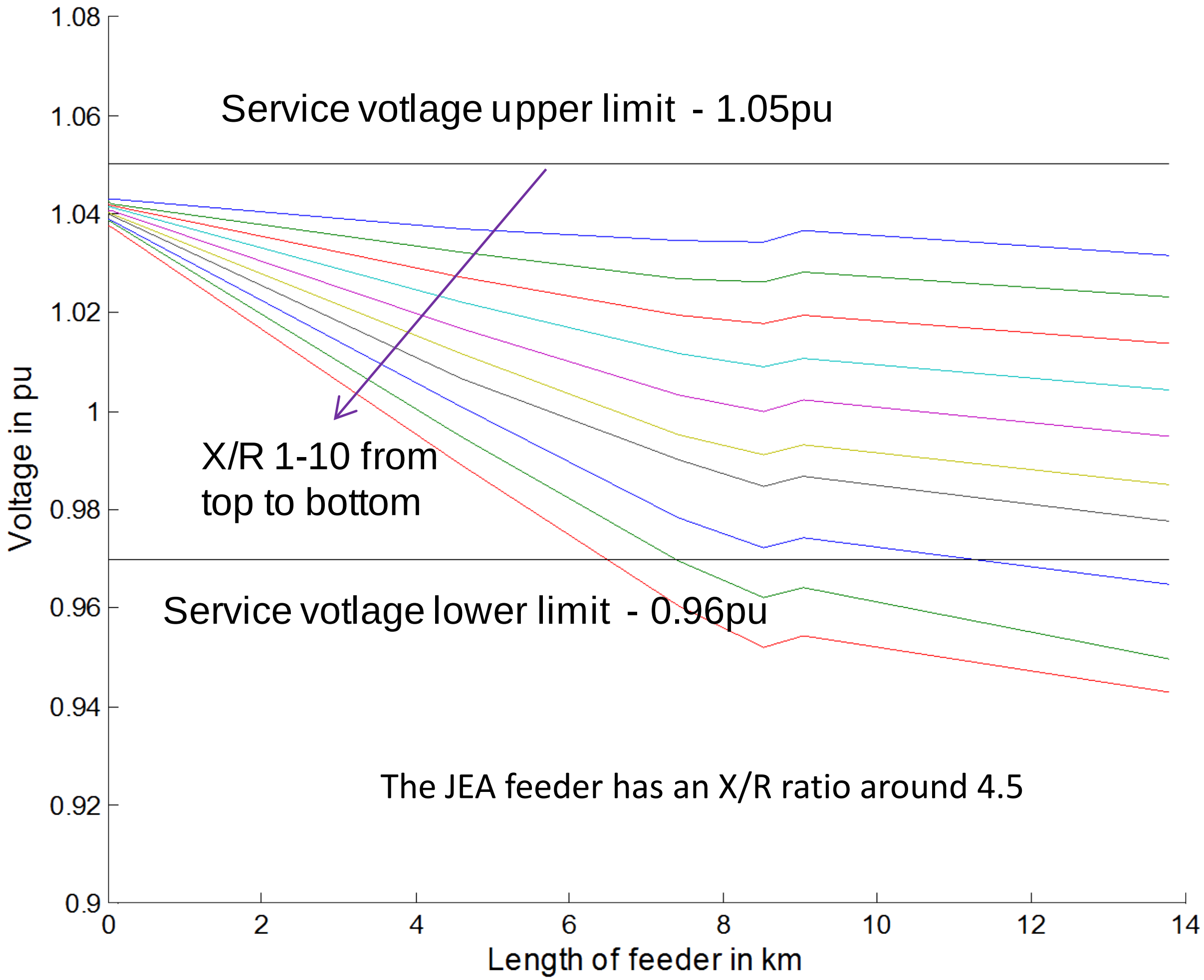
Lakeland Linder
Airport

JEA – PSEG Jacksonville Solar

- 15 MW DC; 12.6 MW AC
- Online Nov. 2009
- Owner: PSEG; under PPA to JEA
- 100 acres
- 24kV distribution feeder
- 230kV substation
- Feeder length : 9 miles
- PV location: 4.8 miles
- Max. ckt. load <12.6 MW
- Inverters (20):
  - SMA Sunny Central 630 HE
- Panels (~200,000):
  - First Solar FS-275

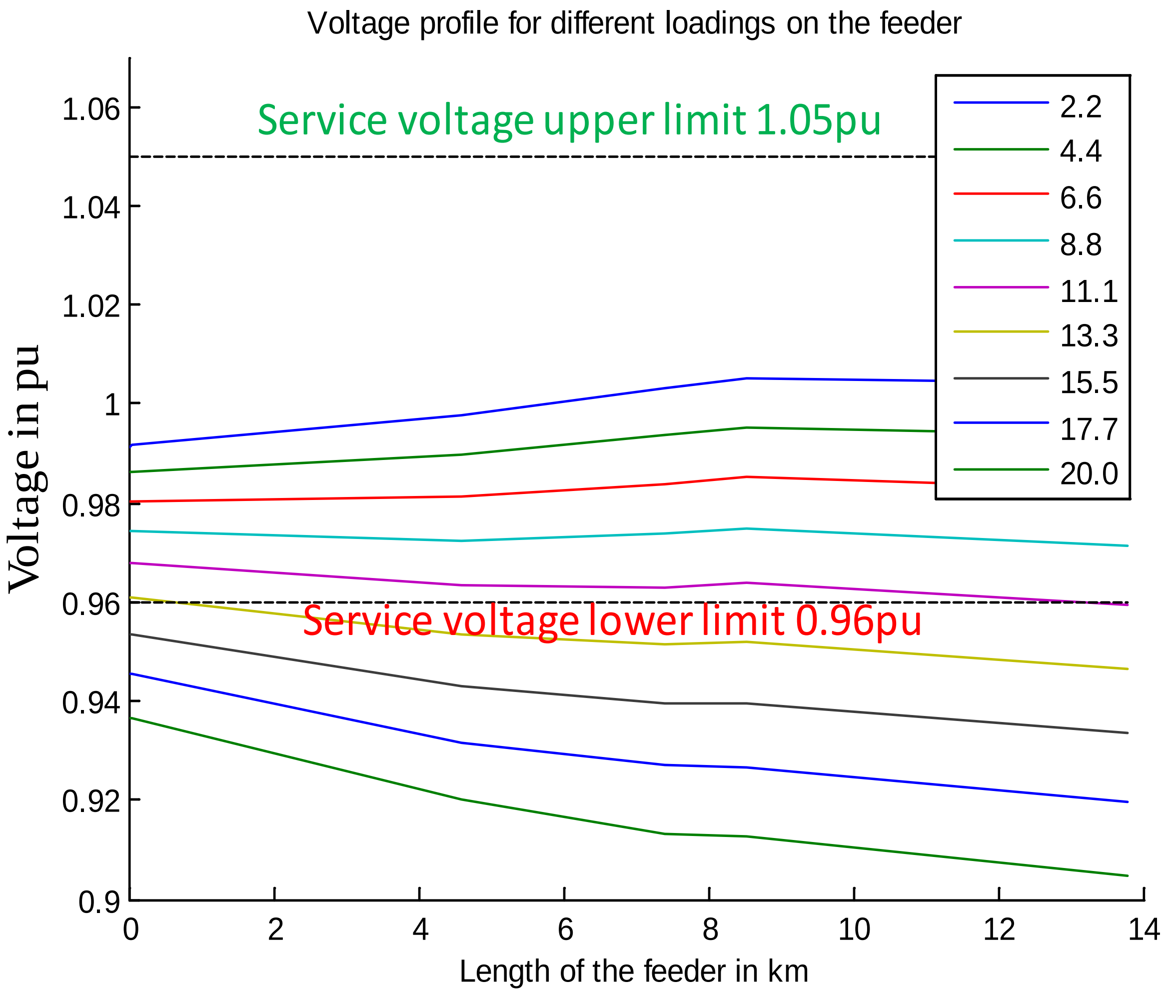


Impact of Different X/R Ratios



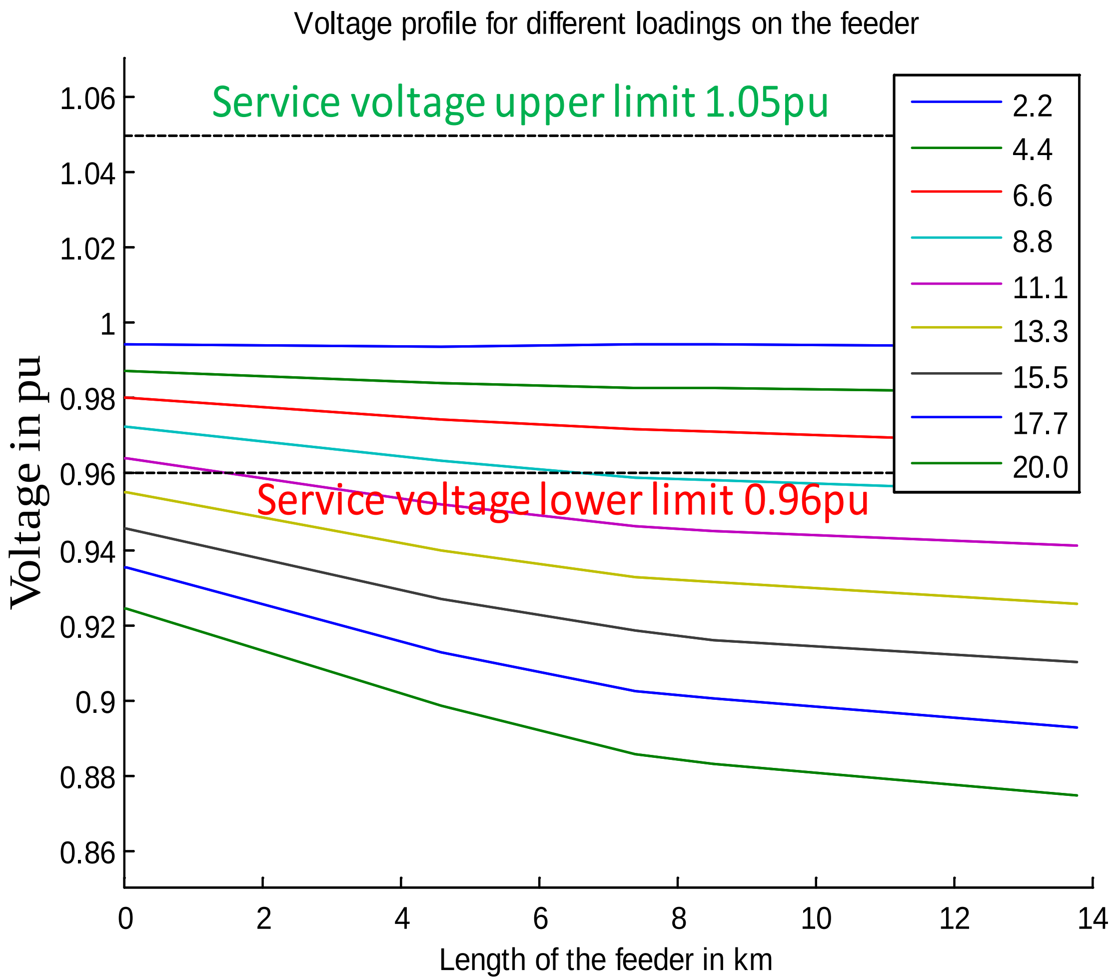
Impact of Different Loading

High PV Production



PV power at 12 MW

Impact of Different Loading
Low PV Production

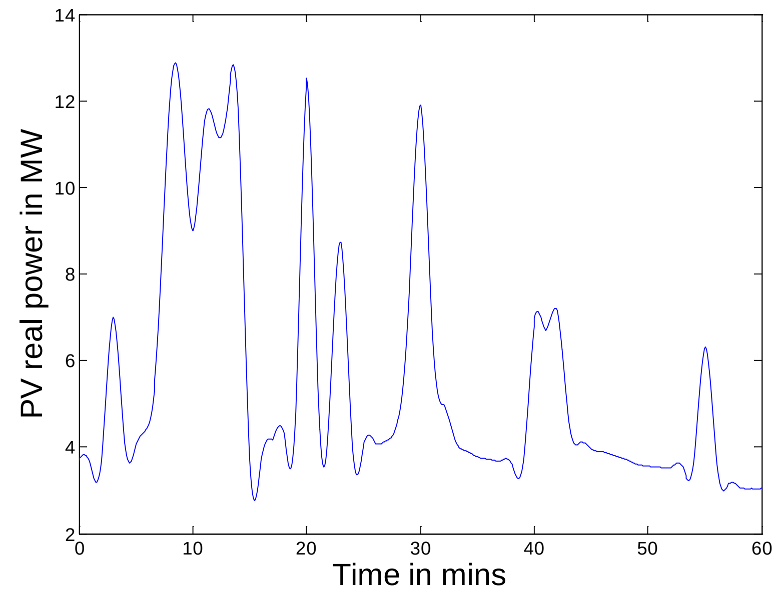


PV power at 3 MW

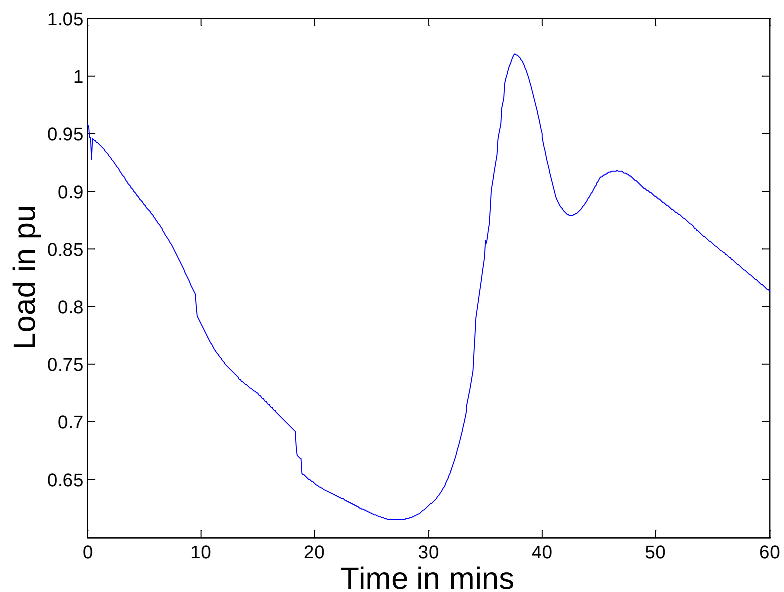
Examining voltage regulation on JEA feeder

- PV Power Profile
  - Used Lakeland, FL Data
  - PV power data (DC power) fed at every five (5) sec
  - PV power profile was scaled up to match the PV plant output rating.
- Load peaks at 15.5 MVA

  (vs normally <12 MVA)
- Case studies focused on the independent operation of
  - OLTC,
  - Switched Capacitor Bank
  - PV at voltage controlling mode and
  - Simultaneous operation of all of them



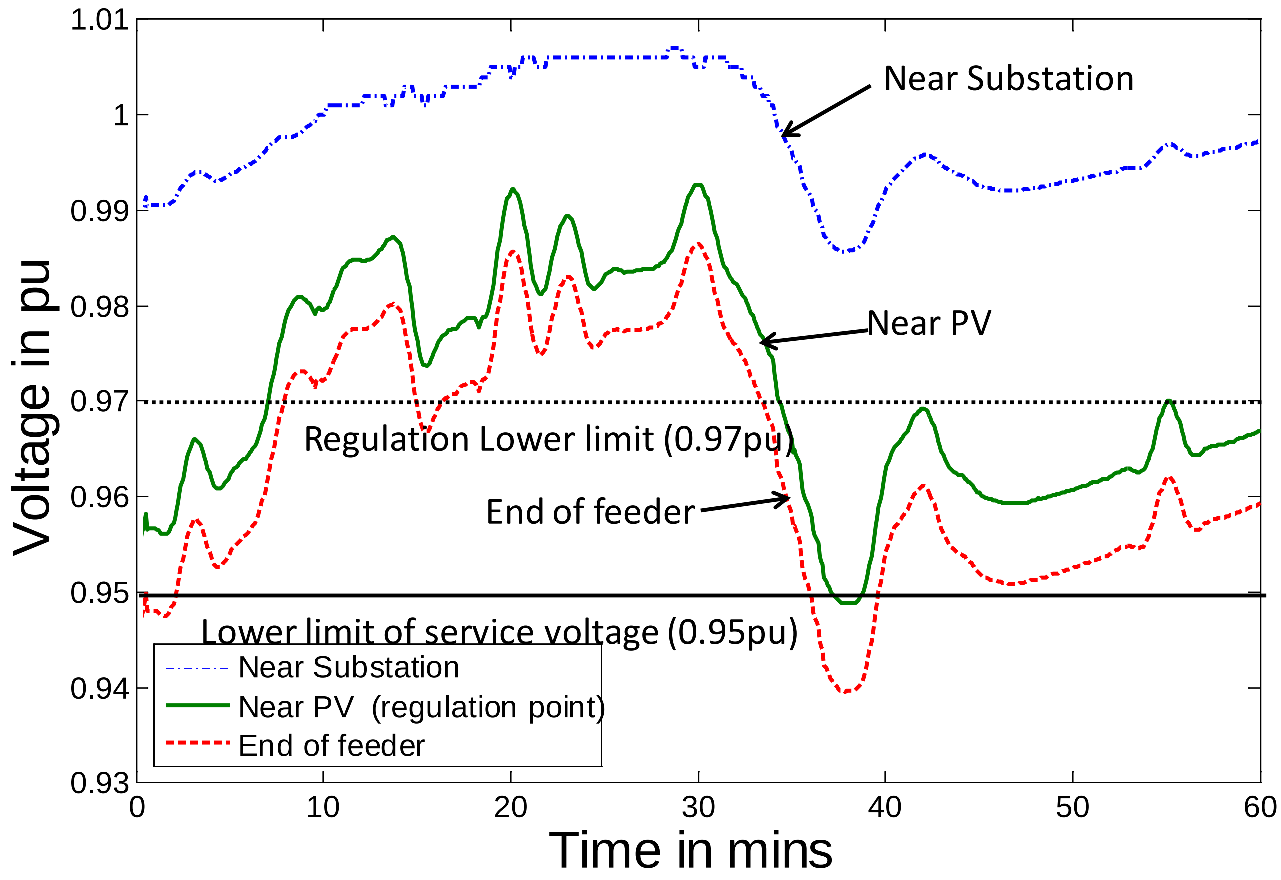
PV power profile used



Load profile used

Examining voltage regulation options - Base Case: no voltage regulating equipment

- The simulation case studies with single large PV plant (12.6MW),
- PV located at mid point on feeder (4.5 miles from substation)
- For study, loading goes higher than actual feeder, but within transformer rating



Voltage Regulation Equipment Interaction study

OLTC

- Set to regulate voltage at the midpoint of the feeder.
- Initial wait time 30sec. Time delay for each tap change 1sec
- Transformer regulation limits +-10% with 0.625% step size

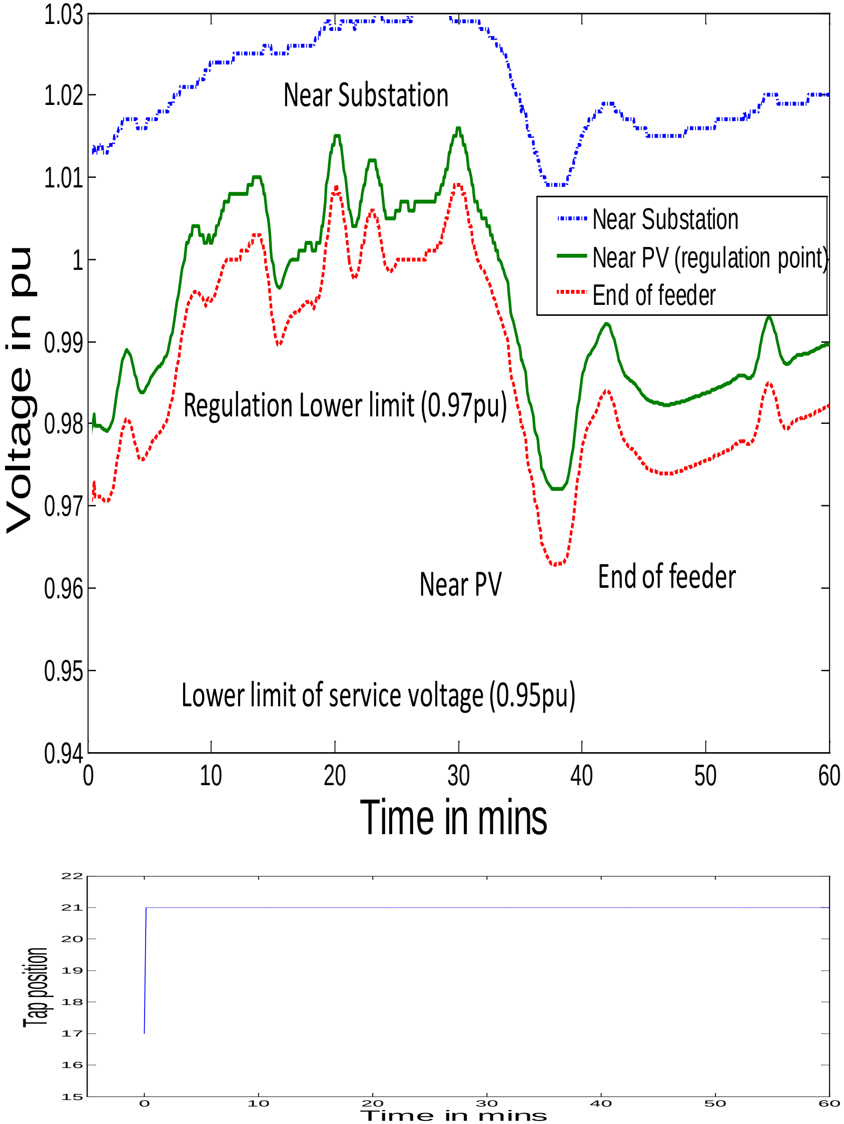
Switched capacitor bank

- 8 filter banks with total rating of 6MVA was placed at the midpoint of the feeder
- Each bank switch has a delay of 5sec
- Capacitor bank set to operate for if the voltage goes below a certain limit

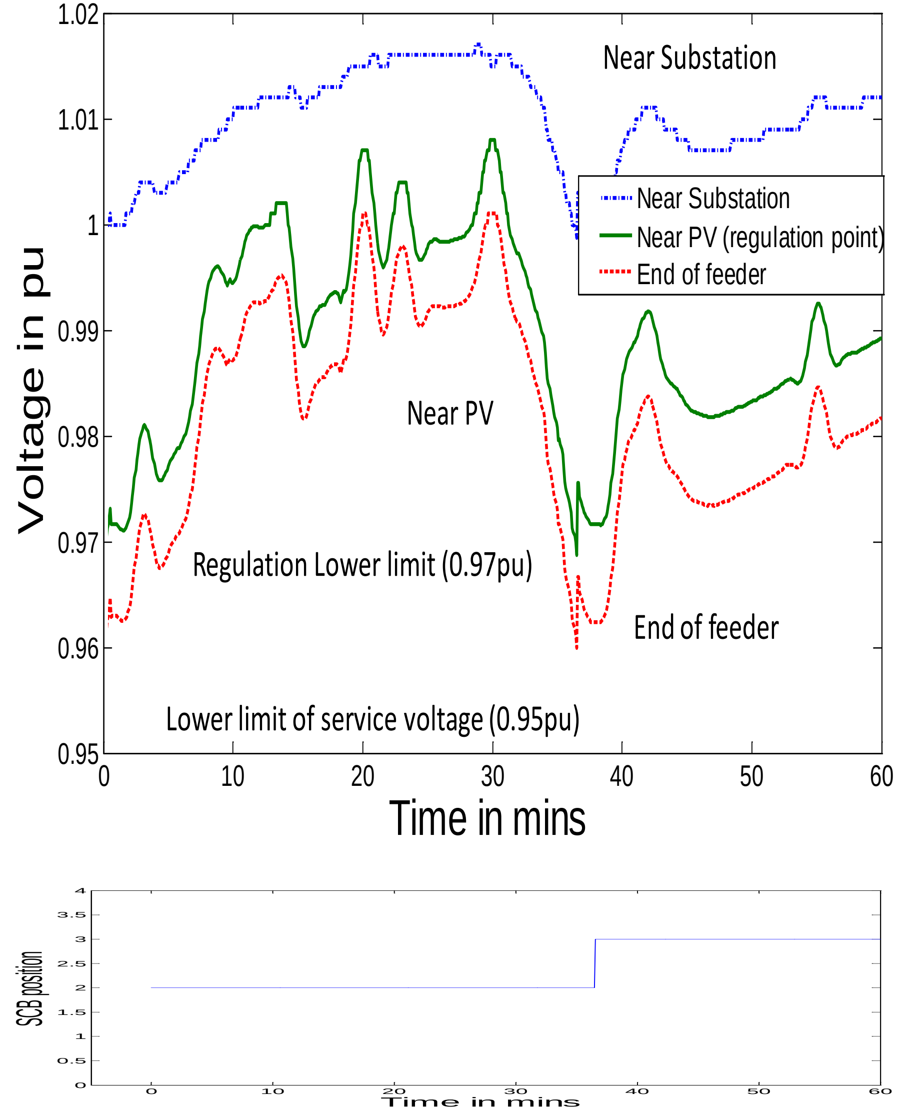
PV inverter system

- Average model of PV plant built
- PV system rated at 13MVA
- PV reactive power support limited by the system rating and real power at that instant.

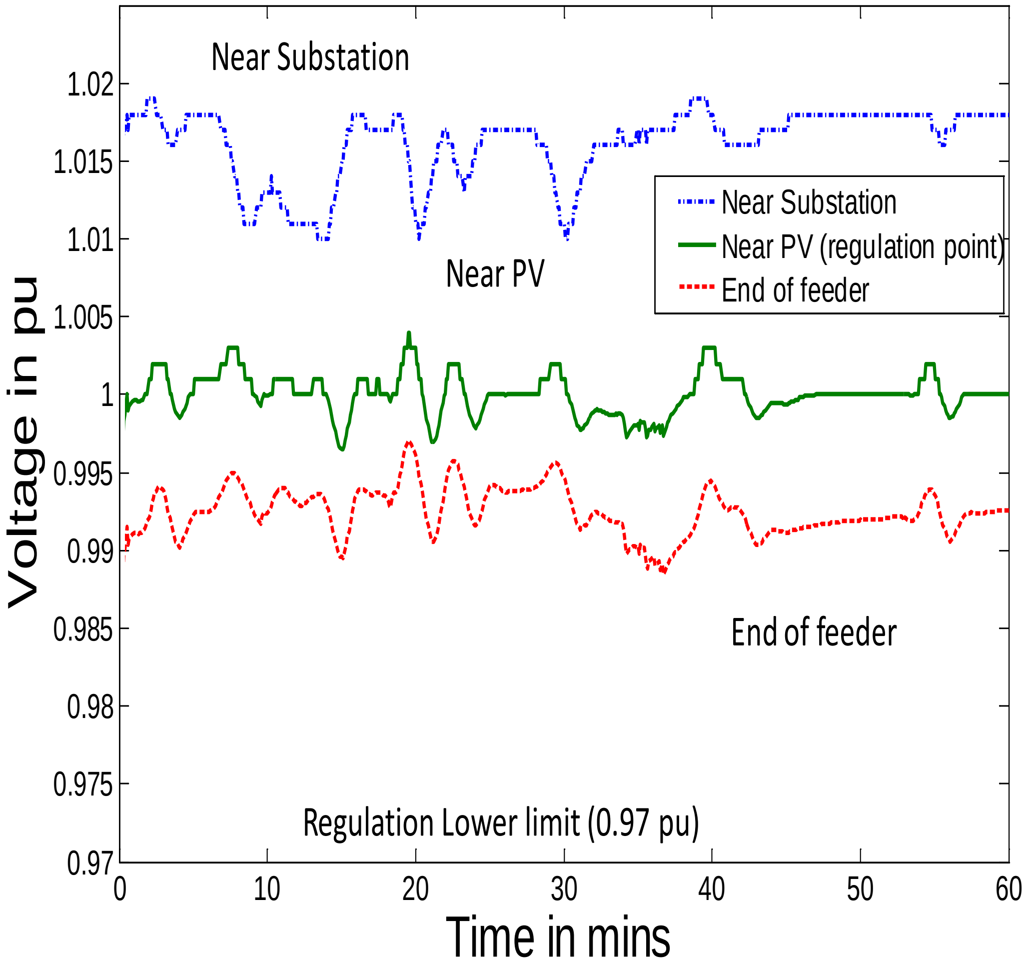
Voltage profile with OLTC only



Voltage profile with SCB only

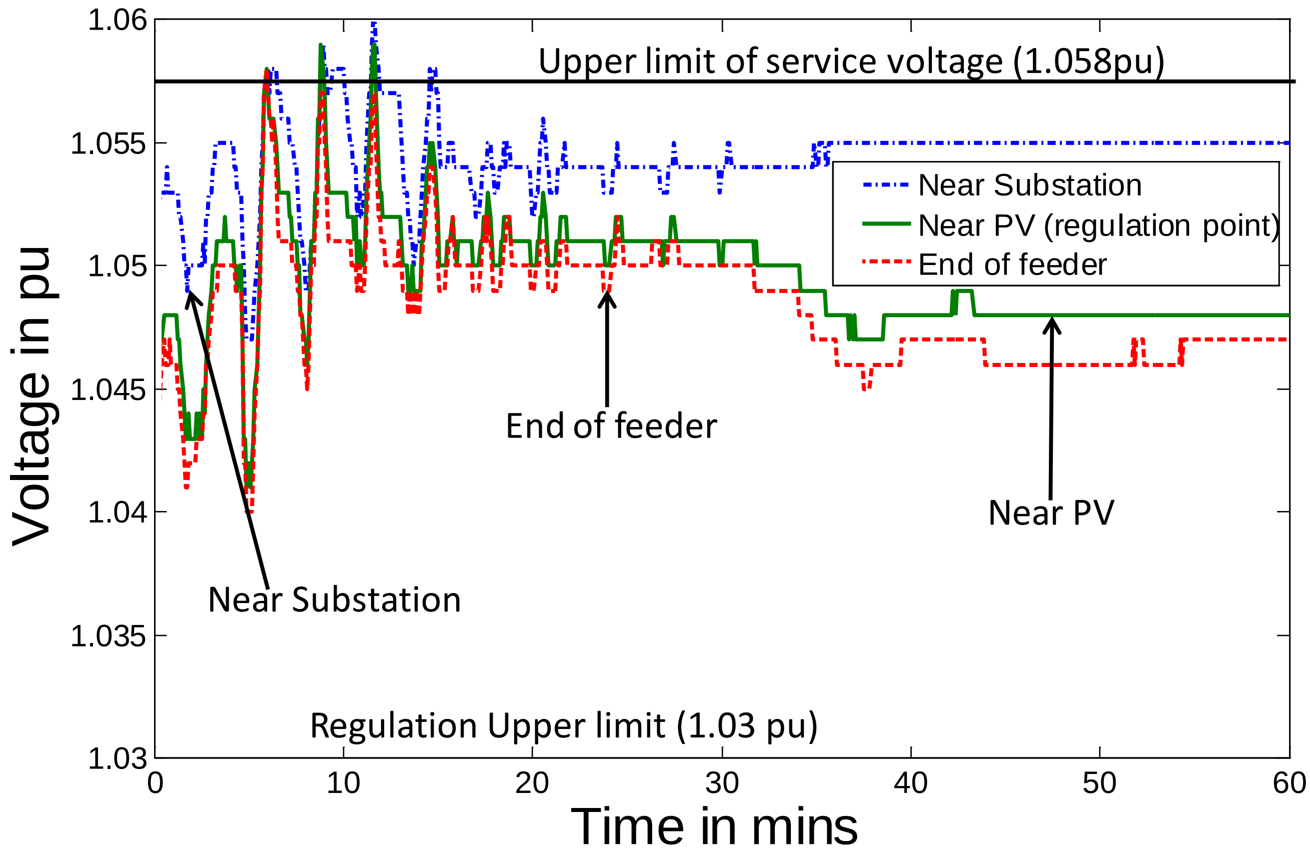


Voltage profile with Single 12.6 MWAC PV plant controlling the voltage



- PV controls the voltage at PCC to 1:00 pu
- PV reactive power supply in P priority mode (has not reached to its limit)
- Small fluctuation is due to the sharp changes in the PV power and load profile

Voltage profile for PV controlling the voltage – Multiple PV Units



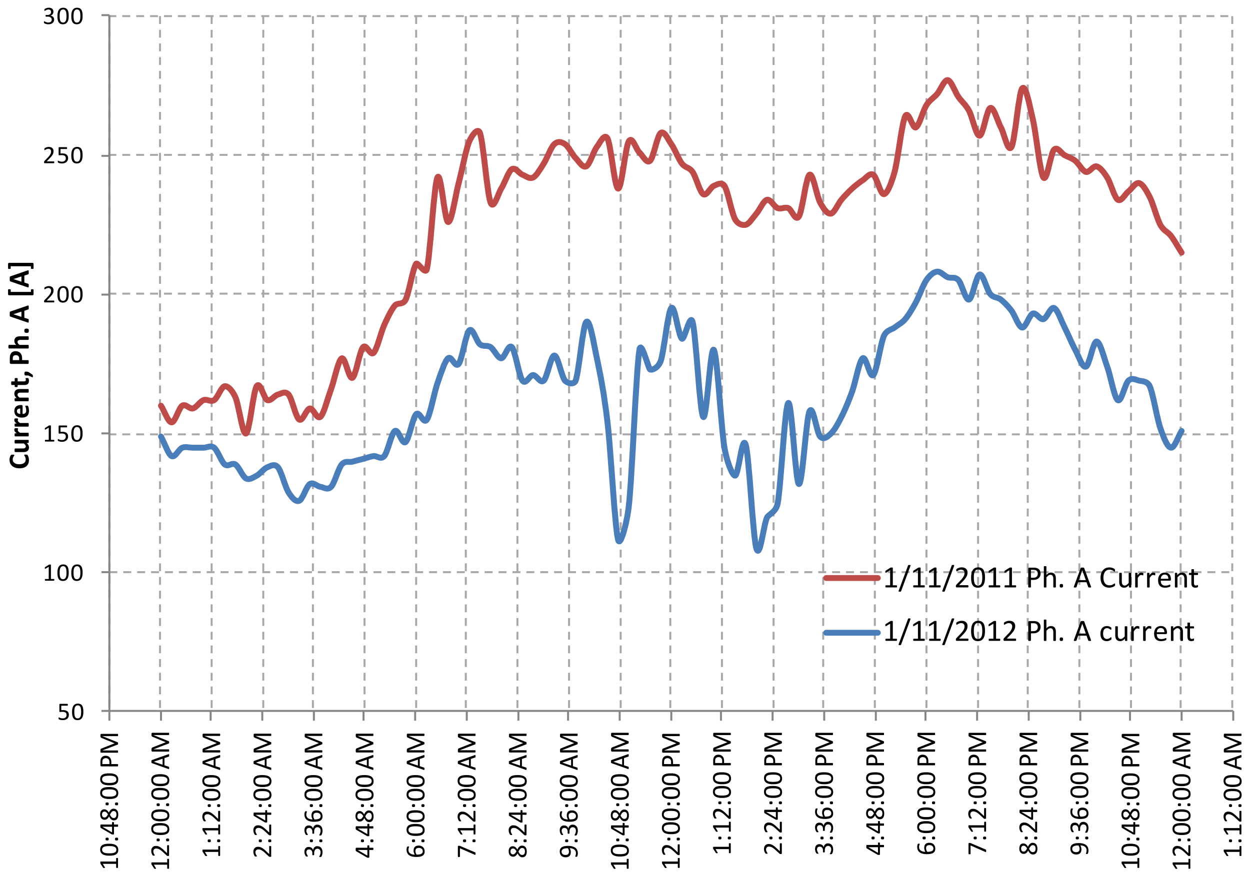
- The PV system regulates the voltage at each PCC to 1pu (low side of utilization transformer)

A Municipal Utility Feeder

- 12.47 kV circuit with overhead primary about 4.5 miles.
- Peak loading on the feeder 9 MVA.
- Peak PV installed capacity 2.6MW distributed:
- Recloser at around 2.2 miles from substation.
- Four cap banks installed on the circuit
- Voltage regulator installed near substation.
- A fairly typical mix of residential and commercial loads

Winter

before (2011) and after (2012) addition of 2 MW PV plant

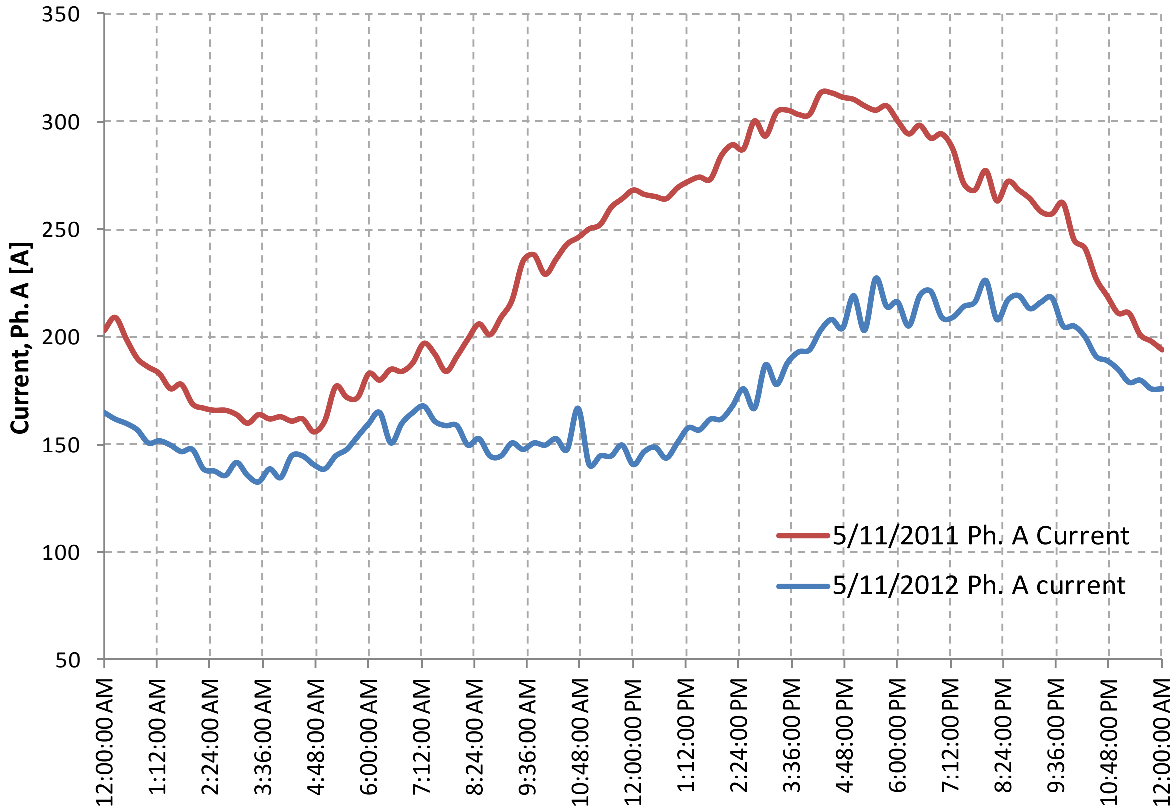


JANUARY 2011	*Ph. A*	*Ph. B*	*Ph. C*
Min.	124	121	136
Max.	363	374	405
Avg	199.3	200.8	216.2
Min/Max	34.16%	32.35%	33.58%
0.5*Min/Max	17.08%	16.18%	16.79%

JANUARY 2012	*Ph. A*	*Ph. B*	*Ph. C*
Min.	66	69	73
Max.	587	515	557
Avg	179.3	180.6	189.8
Min/Max	11.24%	13.40%	13.11%
0.5*Min/Max	5.62%	6.70%	6.55%

Early Summer

before (2011) and after (2012) addition of 2 MW PV plant



Note: May 2012 is based on partial data set – thru 5/18 only

MAY 2011	*Ph. A*	*Ph. B*	*Ph. C*
Min.	118	113	126
Max.	331	363	393
Avg	205.9926	210.0689	226.2758
Min/Max	35.65%	31.13%	32.06%
0.5*Min/Max	17.82%	15.56%	16.03%

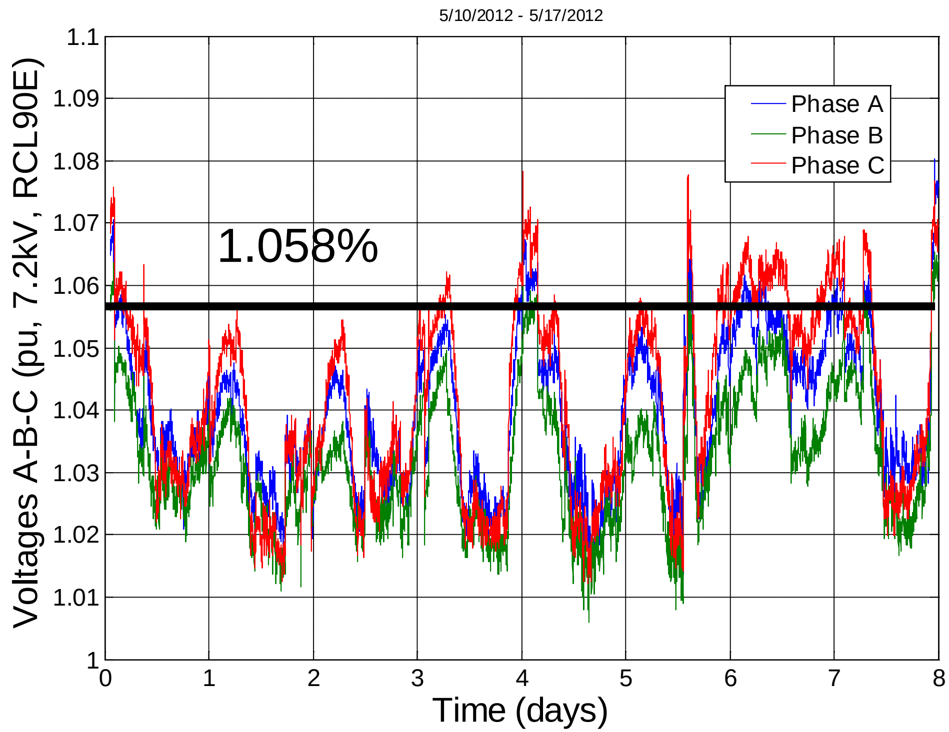
MAY 2012	*Ph. A*	*Ph. B*	*Ph. C*
Min.	97	98	109
Max.	272	305	309
Avg	181.4232	192.2119	199.5429
Min/Max	35.66%	32.13%	35.28%
0.5*Min/Max	17.83%	16.07%	17.64%

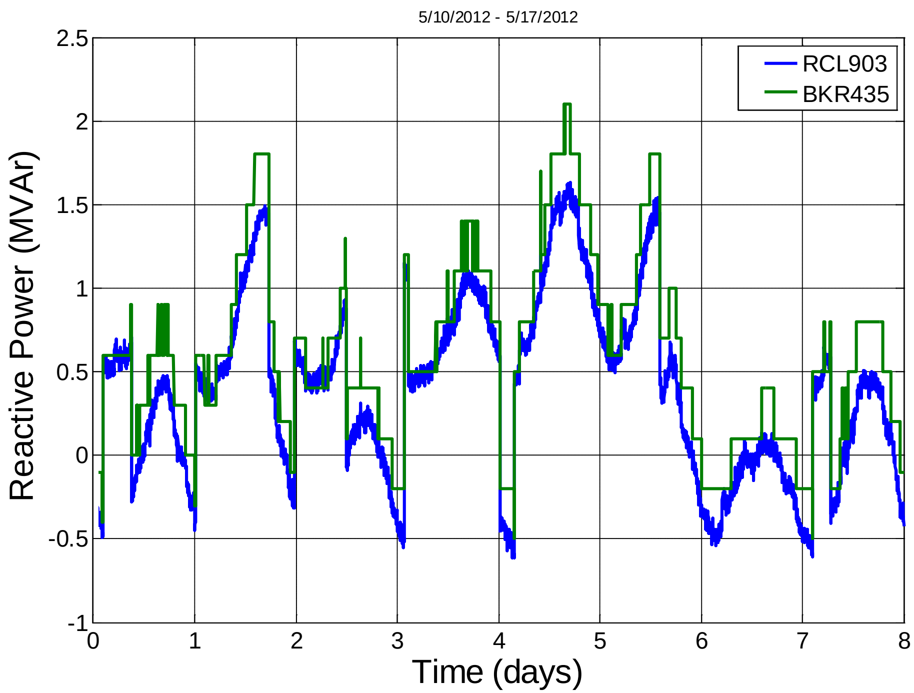
Actual feeder behavior

ANSI C 84.1

Medium Voltage Level	Service Voltage	
	Minimum	Maximum
Range A	-2.5%	+5%
Range B	-5%	+5.8%

Recloser Voltage



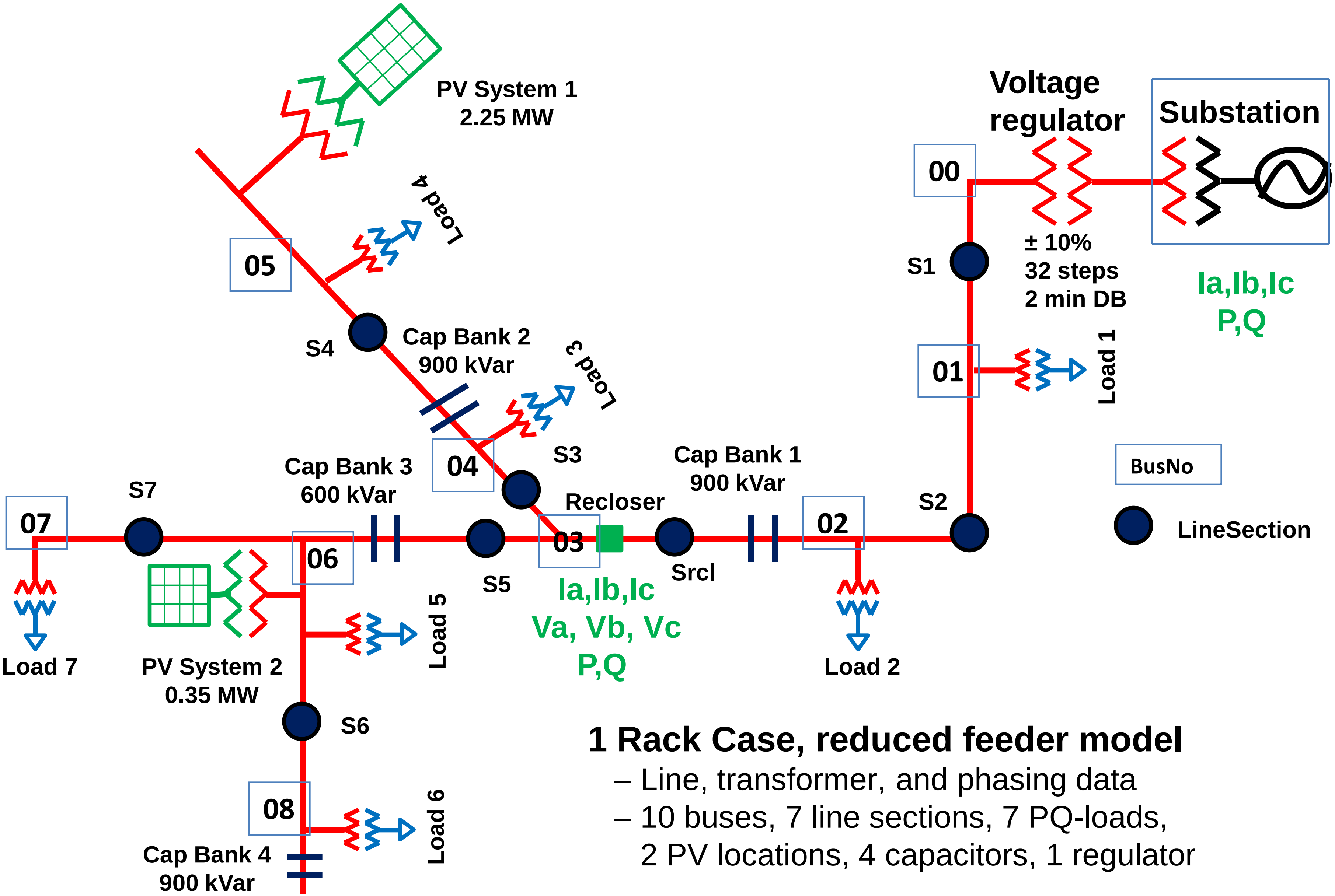


Reactive power flow

Model Development and Validation

- Primary modeling tools:
  - RTDS
  - OpenDSS
- Limited Field Data for Validation

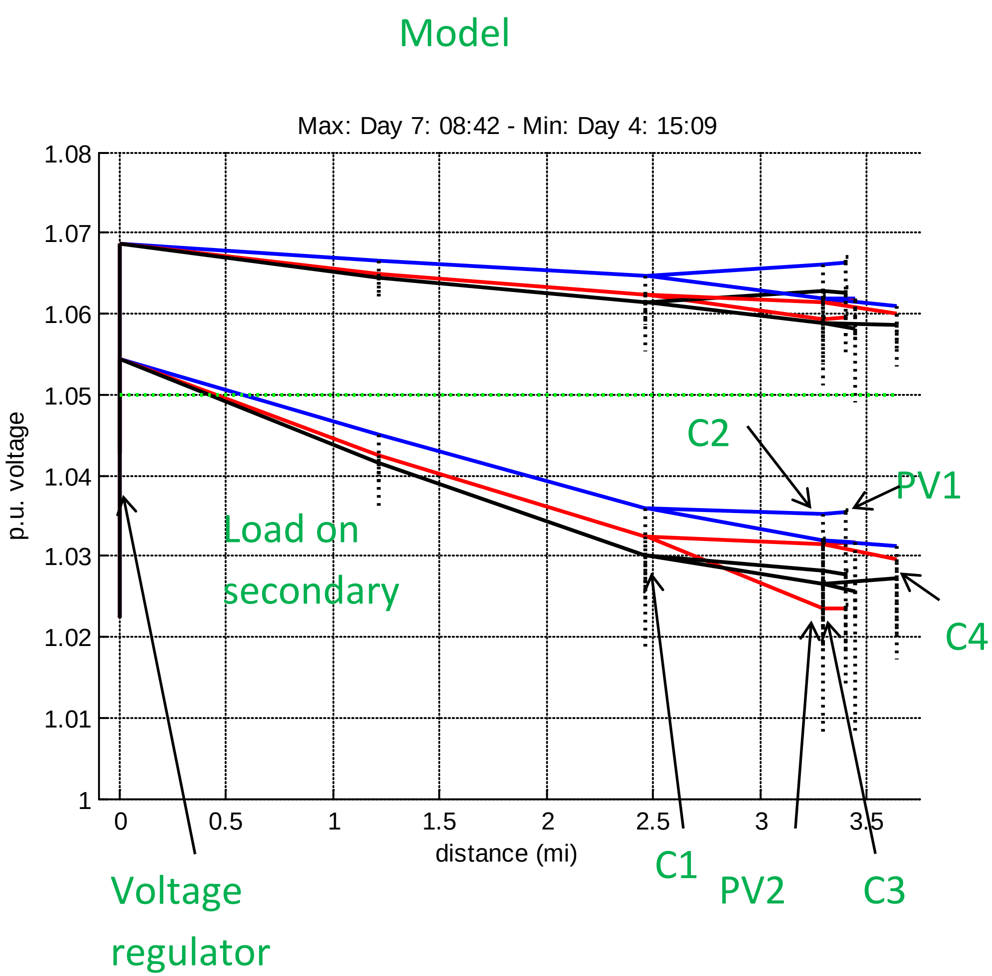
RTDS One rack real time feeder Model



1 Rack Case, reduced feeder model

– Line, transformer, and phasing data
– 10 buses, 7 line sections, 7 PQ-loads,
2 PV locations, 4 capacitors, 1 regulator

OpenDSS Model
Expected Max/Min-Feeder Voltage Profile



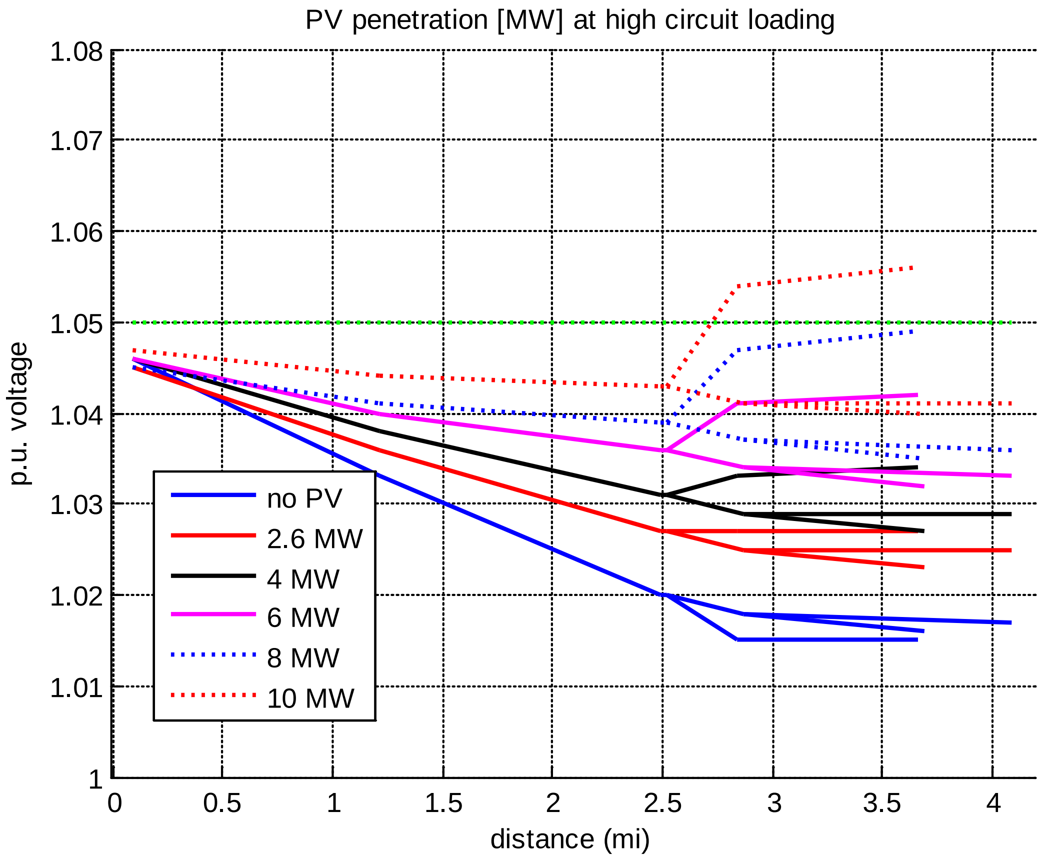
- Current PV level
- Each minute for 8 weekdays
- Sampled load demand (normal distribution)
- Local cloud cover index

•Legend:

- Blue – ph A.
- Red – ph B
- Black – ph C

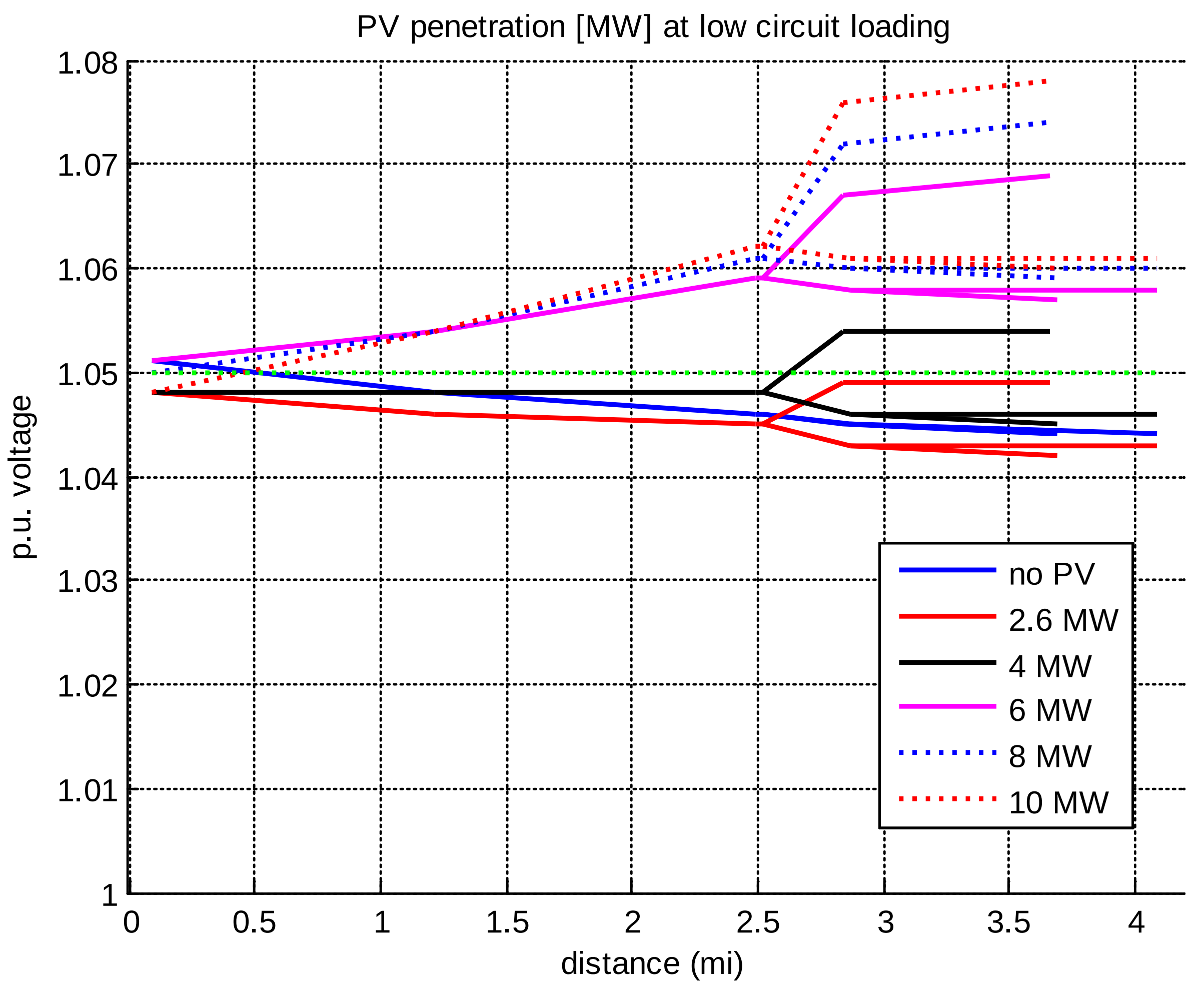
PV Penetration Analysis (with RTDS Model)

High loading scenario – 9 MVA

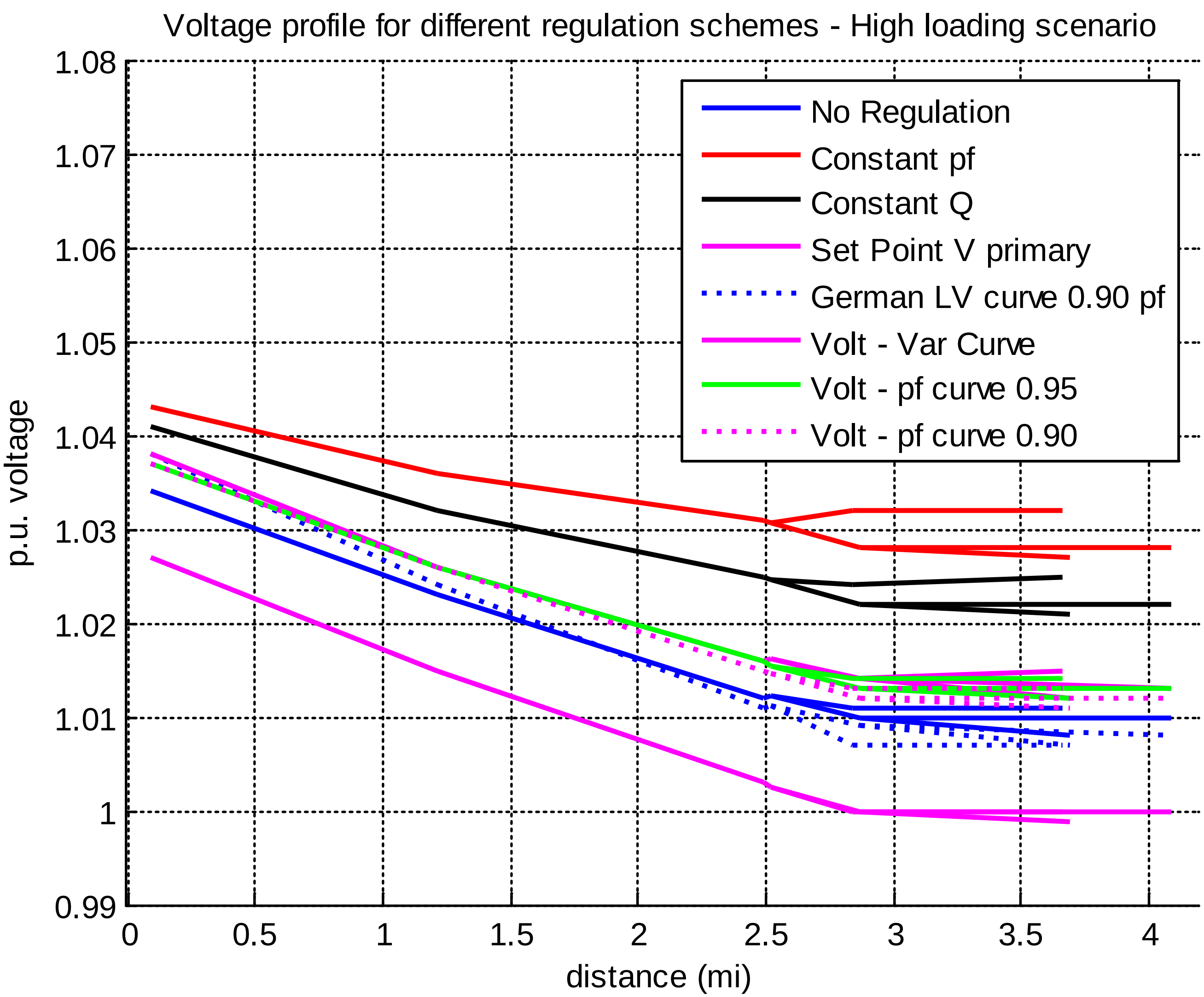


PV Penetration Analysis (with RTDS Model)

Low loading scenario – 4 MVA

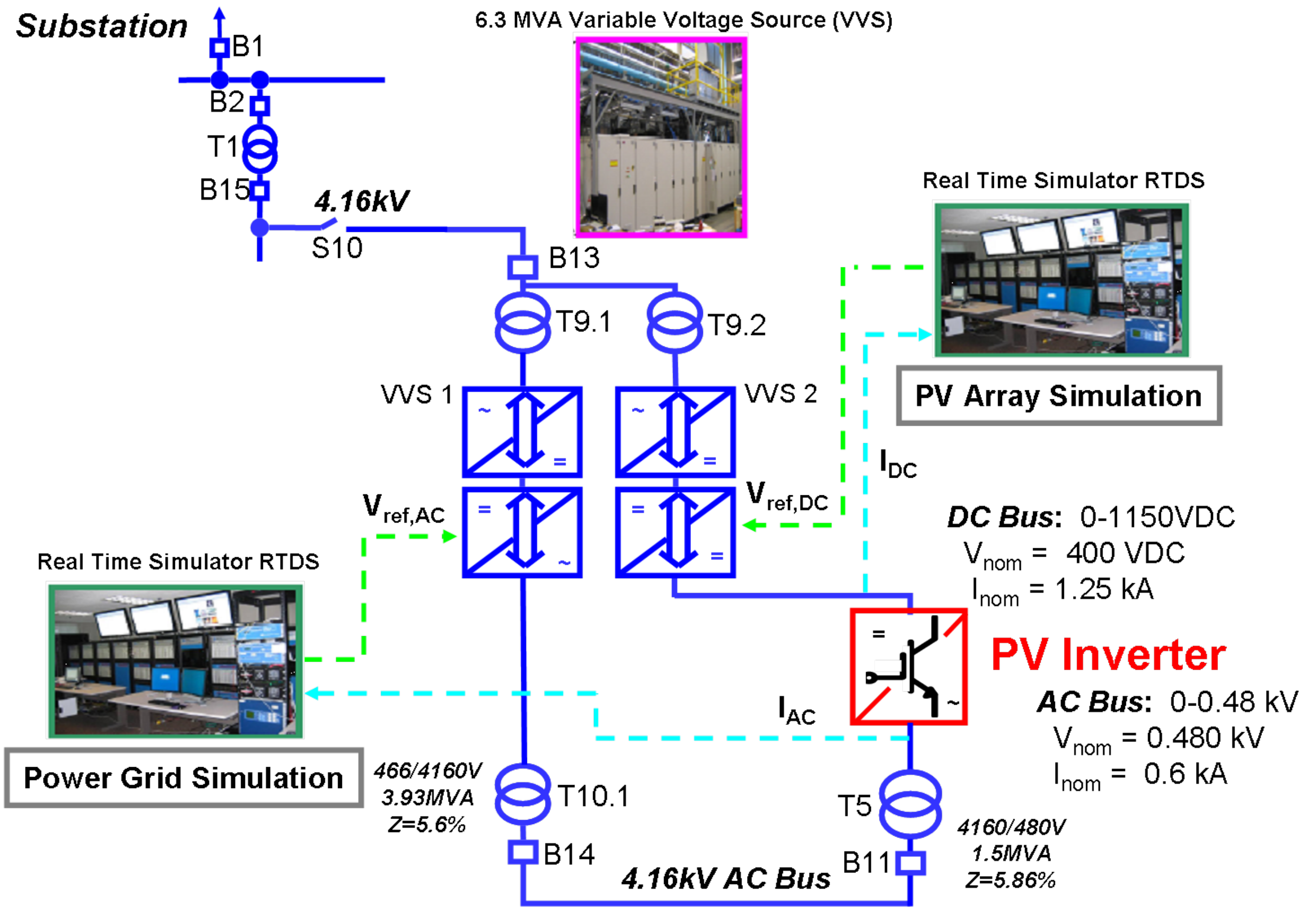


PV Participation in Voltage Regulation
High Loading



High Power HIL Testing of Solar PV Converter, with SCE and NREL

- Power Hardware-in-the-Loop arrangement
  - Direct current source emulates solar PV characteristic
  - Alternating current source emulates distribution feeder at interconnection point
- Experiment design, control, and protection
  - Real-time digital simulator environment
  - De-risking through modeling of converter



Summary
Some Observations from Work-to-date

- Percent penetration and 15% screen is a poor metric
- Seeking a classification of circuit types and more appropriate metrics than % penetration – must look at many circuits first
- Require high fidelity time-series analysis for protection and control issues
- PV can and should be used to aid in regulation
- System dynamics and interaction of regulation equipment can cause issues
- Control and protection schemes, algorithms and settings are significant
- Hardware-in-the-loop simulation is a useful tool for analysis and de-risking

Six Ideas Whose Time Has Come

1. Solar PV providing ancillary services
2. Continuous and advanced control
   – Measurement and communications implications
3. Islanded operation
   – Microgrids
   – DC distribution

Six Ideas Whose Time Has Come

4. Solar capacity credit
   - Reserve / Firm Generation
5. Distributed Energy Zones
   - Utility engagement and benefit
   - Proactive and streamlined
6. Revised playbook
   - Laws, rules and regulations, policies
   - Guidelines and standards
   - On a sound science, engineering, and economics base

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